Optimal Reactive Power Flow through Regulation of Voltage Control Variable

by Zulfatri Aini

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Abstract – **The aim of the research is to optimize reactive power flow through regulation of voltage control variable, so active power losses on transmission line can be minimized while bus voltage profile is on determined limit. The research used data of electrical power system of West Sumatra Area.**

Method used in this research is the simultaneous reactive power injection. The method aims to determine optimal condition and regulate reactive power by improving voltage profile and minimizing active power losses of the system by applying generator output voltage constraint, static var compensator reactive power injection and position of transformer tap ratio with same priority. Change of voltage value based on reactive power injection and impact of transformer tap are observed from result of study of power flow with Newton-Raphson method.

This research obtains decreased power active losses as 7,8 % at peak load case and 0,6% on the low load case. Voltage profile of all busses are established on the determined limit.

Keywords – optimal reactive power flow, control variable of voltage, power loss minimization

I. INTRODUCTION

Background Electrical energy is one of the most important requirement to support human life today. In their daily needs, both in households and businesses, people need electricity. In general, the electrical energy is one of the prerequisites of human life, and the development of human life require additional electrical energy supply. People often claim that economic growth in line with the growth of electric energy supply capacity.

Problems that arise are how to distribute electrical energy continuously and efficiently to consumers with the frequency and voltage constant. On the other hand, the load in the system absorbed in the active power and reactive power can not be arranged with due depending on customer needs. Therefore, a logical consequence of overcoming capacity and quality demands of electricity, strived to keep the new methods of maximizing the power installed or to reduce the loss of electric power and voltage profile improvement. Among them is the injection of reactive power that comes from generators, static var compensators and transformer tap changes simultaneously.

Changes in reactive power flow can cause magnitude of current flowing in a small channel, and therefore contributes to decrease the total losses in the system [9]. Setting the optimal reactive power voltage will operate in areas that have been defined constraints and can produce an optimum condition of the transmission losses from the minimum [8].

There are two kinds of reactive power is inductive reactive power (lagging reactive power) and capacitive reactive power (leading reactive power), which both have opposite signs. Inductive reactive power is the power required to produce a magnetic field by induction tools such as induction motors, transformers, transmission lines and others. Without the inductive reactive power resources can not be transferred to the secondary in a transformer or through the air gap on electric motors. Capacitive reactive power is electric power required by the capacitor, capacitance high-voltage transmission wire, shunt capacitors, synchronous condenser, and others. As we need regulation, reactive power can be used optimally.

Model of reactive power management approach used is the method known as reactive power injection method simultaneously. This method aims to determine the optimal conditions: reactive power settings to improve the voltage profile and minimize power losses in the system, by applying the restraints of the generator output voltage (PV generator reactive adjustment), injection of reactive power static var compensator (static var compensation adjustment) and transformer tap positions (transformer tap adjustment), with the same priority. So the good performance of the system, ie with a maximum working voltage of +5% and -10% minimum of nominal voltage (refer to the Indonesian National Standard/ SNI, No.04-0227-2003) and the minimum load power factor 0.8 [5].

Power flow method used in this study using the approach Newton-Raphson method. While case studies are taken is a system of West Sumatra network. Software to analyze the flow of reactive power is MATLAB Analysis.

II. Review of Literature And Theory

Power flow analysis program with MATLAB which has been developed using the modified Newton Raphson algorithm to the matrix Y bus admittance can determine the voltage levels and losses in the system. Losses calculated using the coefficient B and the proof with the traditional equation of IR^2 or other methods. Control voltage using capacitor bank switching or transformer tap changer can improve the voltage level that can minimize losses. In this case, the experiment used 5 buses network system. Model of the capacitor banks and tap changers included and defined in the program. Several case studies conducted with different capacitance values and transformer tap settings that are connected to determine the minimum losses in accordance with the voltage level with good results and is suitable to be applied [6].

Comparing two different optimal power flow techniques (OPF) between the voltage securities of voltage collapse. Both use a technique based on optimal multi-object methodology, so that operating costs and losses can be minimized by maximizing the circumstances of the voltage falls [3].

Problem solving simultaneous optimization of reactive resources in the transmission and distribution systems with decoupling analysis of transmission and distribution networks. Assumed to be a source of investments and recognized boundaries. In this limit, a number of optimization objective/multi-objective can be selected (distribution losses, distribution feeder power factor, voltage profile for conservative voltage reduction, transmission losses, transmission capacity, voltage stability, etc.). Using Genetic Algorithm as multi-objective optimization tool relies on reducing the sensitivity to Search for. The result of this method applied to model large systems [1].

Voltage regulation problems are mostly influenced by the value of the impedance in the electric power system. Voltage will fall very low on a big burden. When the voltage source is increased and the burden will fall too low voltage condition may occur more. Anticipation of this condition is usually fitted to the impedance compensation or compensation for the lower voltage due to the impedance. Impedance changes improve the voltage regulation with the installation of one var compensation [4].

Supplied reactive power calculated based on power flow limit on the channel and limits the voltage on the busbar. Several factors are necessary, consideration in terms of profit and security, economic and reliability and service costs. Supplying reactive power can be made by generators and capacitors. Reactive power supplied by a generator having a fast action but the operating cost is high while the capacitor with a slower action with operating costs and lower installation [2].

Reactive power management in electric power system operation aims to minimize power loss while the transmission line voltage profile at the boundary is always set.

If the amount of reactive power on both nodes has a source of reactive power that can be set up, the voltage profiles obtained which caused losses of at least the system. Allocation of such reactive power is reactive power allocation in terms of optimum allocation of reactive power is to generate power losses are minimal in the system. In searching for these optimum conditions, the limits of resource capabilities and the location of reactive resources are a constraint that must be faced.

The equation for calculating losses on real power transmission network is expressed in the relationship [11] :

$$P_{loss} = \sum_{k=1}^{n} G_k \left[V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)\right] \quad (1)$$

Equation (1) is a non-linear function of the power loss of the bus voltage and used as the objective function (object function) to reduce power losses in the channel. When brought into a linear form of the ΔPL is differentiated by bus i and j, then equation (1), becomes:

$$\frac{\partial P_L}{\partial V_i} = G_k\left[2V_i - 2V_j \cos(\delta_i - \delta_j)\right] \quad (2)$$

$$\frac{\partial P_L}{\partial V_j} = G_k\left[2V_j - 2V_i \cos(\delta_i - \delta_j)\right] \quad (3)$$

Based on the equation (2) and (3) to obtain the relationship change real power loss of the large voltage ΔPL is:

$$\Delta P_L = \left[\frac{\partial P_L}{\partial V_i} \cdots \frac{\partial P_L}{\partial V_j} \cdots \frac{\partial P_L}{\partial V_{nb}}\right] \begin{bmatrix} \Delta V_1 \\ \Delta V_2 \\ \cdots \\ \Delta V_{nb} \end{bmatrix} \quad (4)$$

Liniearized objective function which is used to reduce the loss of real power to regulate keluran voltage generator, a large injection of reactive power capacitors, and transformer tap positions simultaneously.

Inhibition functions in the control variable voltage settings as a requirement to reduce losses is to limit the bus voltage and limits the potential power generating reactive power (generator buses and reactive power sources) and the width of the transformer tap, these restrictions when expressed in equation are:

$$V_{i.j}^{\min} \le V_{i.j} \le V_{i.j}^{maks}$$

$$Q_i^{\min} \le Q_i \le Q_i^{maks}$$

$$\Delta T_{i.j}^{\min} \le \Delta T_{i.j} \le \Delta T_{i.j}^{maks}$$

The relationship between changes in reactive power generator voltage change is also seen as a linear relationship. The amount of reactive power injection at generator bus is:

$$Qi = Vi \sum_{j=1}^{n} V_j Y_{ij} \sin(\delta_i - \delta_j - \theta_{ij}) \quad (5)$$

Linear relationship between the magnitude of reactive power injection at each bus with voltage change is written:

$$\Delta Q = M.\, \Delta V \quad (6)$$

The coefficient M is the Jacobian matrix that determines control of reactive power by incorporating the influence of transformer tap.

$$\begin{aligned} \Delta P_L = {} & \frac{\partial P_L}{\partial V_1}.\Delta V_1 + \frac{\partial P_L}{\partial V_2}.\Delta V_2 + \ldots\ldots \frac{\partial P_L}{\partial V_m}\Delta V_m \\ & + \frac{\partial P_L}{\partial Q_1}.\Delta Q_1 + \frac{\partial P_L}{\partial Q_2}.\Delta Q_2 + \ldots\ldots\ldots \frac{\partial P_L}{\partial Q_m}.\Delta Q_{m+x} \\ & + \frac{\partial P_L}{\partial T_1}.\Delta T_1 + \frac{\partial P_L}{\partial T_2}.\Delta T_2 + \ldots\ldots\ldots \frac{\partial P_L}{\partial T_k}.\Delta T_k \end{aligned} \quad (7)$$

with,

V: voltage bus from the bus until the bus no.1 no. m of nodes that have a generator.

Q: reactive power from the node no. 1 to the node no (m + x) for both nodes have a capacitor or a reactor.

T: no.1 transformer tap position to tap the transformer no. k, for the transformer can be arranged at her position.

equation (7) can be transformed to the form,

$$\Delta P_L = \left\{ \left[\frac{\partial P_L}{\partial V_m}\right] \left[\frac{\partial P_L}{\partial Q_{m+x}}\right] \left[\frac{\partial P_L}{\partial T_k}\right] \right\} \begin{Bmatrix} [\Delta Vn] \\ [\Delta Q_{m+x}] \\ [\Delta T_k] \end{Bmatrix} \tag{8}$$

$\left[\frac{\partial P_L}{\partial V_m}\right]$ is a vector that describes the loss of sensitivity to changes in voltage concluded no. 1, 2 ...., N, i.e all nodes that have a generator.

$\left[\frac{\partial P_L}{\partial Q_{m+x}}\right]$ is a vector that describes the loss of sensitivity to changes in voltage at node no. m +1, m +2, ..., m + x, which has a source of reactive power capacitor or reactor. In contrast to the node that has a generator, the node has a capacitor or reactor can not set the voltage, but can only be regulated reactive power injection, whereas the node that has a generator, which is a voltage regulated.

$\left[\frac{\partial P_L}{\partial T_k}\right]$ is a vector that describes the loss of sensitivity to changes in transformer tap.

To provide the necessary operational limits constraints, both for variables and for variables set regulator can be expressed mathematically as follows:

$$\begin{array}{c} \text{variable limi} \\ \\ \text{boundary with contr} \end{array} \begin{bmatrix} \Delta Q^{min} \\ \vdots \\ \Delta Q_m^{min} \\ \Delta V_{m+1}^{min} \\ \vdots \\ \Delta V_m^{min} \\ \Delta T_{pq}^{min} \\ \Delta V^{min} \\ \vdots \\ \Delta V_m^{min} \\ \Delta Q_{m+x}^{min} \end{bmatrix} \leq \begin{bmatrix} S_1^* \\ S_2^* \\ S_T \end{bmatrix} \begin{bmatrix} \Delta T_{pq} \\ \Delta V \\ \vdots \\ \Delta V_m \\ \Delta Q_{m+1} \end{bmatrix} \leq \begin{bmatrix} \Delta Q^{maks} \\ \vdots \\ \Delta Q_m^{maks} \\ \Delta V_{m+1}^{maks} \\ \vdots \\ \Delta V_m^{maks} \\ \Delta T_{pq}^{maks} \\ \Delta V^{maks} \\ \vdots \\ \Delta V_m^{maks} \\ \Delta Q_{m+x}^{maks} \end{bmatrix} \tag{9}$$

a. 1 ...... : index node that has a generator

b. m+1 ..... $m+x$: index node that has a non reactive power source generators

c. Q_1 ..... Q+m : generated reactive power generator

d. V_{m+1} ..... V_n : node voltage generators that do not have (non reactive resource generator)

e. T_{pq} : transformer tap positions between the node p and node q

f. V_1 ..... V_m : voltage nodes has a generator

g. Q_{m+x} : generated reactive power non generator node

h. S : sensitivity matrix (the inverse of the Jacobian matrix)

c and d is a set of variables (state variable), while e, f, and g is a variable regulatory (control variables).

III. Research Methodology

Materials research is to optimize the flow of reactive power in West Sumatra, system using the generator output voltage settings (PV generator reactive adjustment), the installation var compensator (static var compensation adjustment) and tap transformer (transformer tap adjustment). Thus reducing power losses and improving voltage profile. Data taken from the network UPB PT. PLN West Sumatra, and then analyzed using MATLAB programming.

With reference to some literature and articles, as well as utilizing the data obtained from UPB PT. PLN West Sumatra and the data processed by MATLAB simulation to see the performance of the system simulation and calculation results in the appearance.

Data of channels: channels, unit, type, length and conductivity capacity transmission line, voltage and capacity KV KVA / MVA per transformer, the impedance values (R and X) of each branch

- Data of load : load of capacity (MW dan MVAR).
- Generating data include: active power (MW) and reactive power (MVAR) generated by the power generating capacity installed on, the voltage (kV) power.

IV. RESULT

The result of this study is in the form of EDSA program execution, with data taken from research UPB PT. PLN West Sumatra, consisting of 7 power centers that serve the load distributed in the Province of West Sumatra.

System used to analyze the data load on the low load conditions and peak (night).

The main focus of this research is to optimize the reactive power flow through the variable voltage regulator that is: the generator output voltage settings (PV generator reactive power adjustment), reactive power injection through a capacitor (static var compensation adjustment) and transformer tap settings simultaneously. The power losses in the system can be reduced while the voltage profile can be kept constant. Thus the system performance will be good.

This setting produces the values of the new regulatory variables, which can reduce power losses and improving voltage profile at each bus to a predetermined limit ($0.9 \le Vi \le 1.05$).

This analysis is done by making the system configuration MATLAB software, and perform data entry taken from the field. Then the power flow analysis is using Newton-Raphson method.

Power flow analysis to produce a variety of information including the number of generation, the total losses, donations swing bus into the system, the total load to be supplied as the system in Table 4.1, the buses that have a voltage drop and voltage restrictions are still in the restraint shown in Table 4.2 peak load conditions.

TABLE 1. RESULTS OF THE ANALYSIS INITIAL POWER FLOW

Peak Load				
No.		P (MW)	Q(MVAR)	S(MVA)
1.	Swing Bus	61,191	80,667	101,250
2.	Generation	450,500	170,397	481,648
3.	Load	495,250	166,100	522,361
4.	Losses	16,442	84,967	-

In Table 4.1 shows the power flow analysis before doing the variable regulator settings. From the results of power flow analysis is obtained information about the state of the system.

a Voltage profile

Here can be seen the value of the voltage at each bus and bus-bus voltage failure, as listed in Table 4.2.

TABLE 2. VOLTAGE PROFILE BEFORE AND AFTER SETTING

BUS ID	LOAD PEAK		
	V_{OLD} (pu)	V_{NEW} (pu)	DROP (%)
B_BTSKR	0,9865	1,0088	1,35
B_GPDGLR	0,9657	0,9914	3,43
B_INDRG	0,9651	0,9872	3,49
B_LBALG	0,9722	0,9958	2,78
B_MJU	0,9696	0,9952	3,04
B_OBLN	1,0001	1,0187	0,00
B_PIP	0,9680	0,9913	3,20
B_PLIMO	0,9655	0,9881	3,45
B_PYBUH	0,9756	1,0009	2,44
B_SALAK	0,9984	1,0170	0,16
B_SHARU	0,9574	0,9802	4,26
B_SNKRK	0,9788	1,0025	2,12
B_SOLOK	0,9808	1,0010	1,92

Not : voltage under the constraints ($0.90 \le V_i \le 1.05$)

TABLE 3. VALUE OF REACTIVE POWER AFTER SETTING

PEAK LOAD						
No.	BUS ID	QG (EXT)	QG (NEW)	D(QG)	QG MAX	QGMIN
1.	G_AGAM	0,0481	0,0491	0,0010	0,0840	-0,0630
2.	G_MJU	0,3780	0,3787	0,0007	0,5200	-0,3800
3.	G_PLIMO	0,3550	0,3555	0,0004	0,4800	-0,3600
4.	G_SNKRK	0,1504	0,1509	0,0005	1,0800	-0,8200

With tap changing transformers, reactive power generation of each generator and the capacitor value that is placed on the bus, it can improve the voltage profile to meet the existing constraints.

b. Loss of active power in West Sumatra system.

In Table 4.4, shows the power flow analysis results after the variable regulator settings.

TABLE 4. POWER FLOW ANALYSIS RESULTS AFTER REPAIR

Peak Load				
No.		P (MW)	Q(MVAR)	S(MVA)
1.	Swing Bus	59,987	68,813	91,289
2.	Generation	450,500	170,851	481,809
3.	Load	495,250	164,283	521,787
4.	Losses	15,237	75,381	-

By comparing the results of power flow analysis before (Table 4.1) and after setting (Table 4.4), the losses decrease the total power.

The results of power flow analysis before the regulation, the total real power loss in case of system peak load of 16,422 MW, after setting was reduced to 15,237 MW, which means that power losses decreased channel 1.2 MW (7,8%). It is the same as the case of light load. For clarity can be seen in Table 4.5. Injection of reactive power from generators and static compensators and transformer tap changes enable the achievement of a reduction in losses of active power is significant.

TABLE 5. TOTAL POWER LOSS IN THE SYSTEM BEFORE AND AFTER SETTING

No.	Condition	Total loss of Active and Reactive Power			Losses reduction	Improve-ment (%)
Peak Load						
1.	Before	P (MW)	:	16,442	-	-
		Q(MVAR)	:	84,967	-	-
2.	After	P (MW)	:	15,237	1,20	7,8
		Q(MVAR)	:	75,381	9,58	13

The decrease of power losses in each channel varies with different loading levels. This is in accordance with the characteristics of the voltage profile at each bus is large enough impact on the value of power losses that occur.

V. CONCLUSION

Optimal reactive power flow through voltage control variable settings can minimize the loss of a few percent of the active power and improve the voltage to the specified limits ($0.9 \leq Vi \leq 1.05$).

Losses decrease active power in the system for 1.20 MW (7,8%) for the case of peak load and 0.12 MW (0.6%) in the case of low load.

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